Parks Canada-Technical Reports in Ecosystem Science
Parcs Canada-Rapports techniques en matière de sciences des écosystèmes

National Parks and Historic Sites | Parcs nationaux et lieux historiques

Mercury Concentrations in Yellow Perch (*Perca flavescens*)

from 24 Lakes at Kejimkujik National Park, Nova Scotia

Jennifer Carter,
Clifford Drysdale,
Neil Burgess,
Stephen Beauchamp,
Guy Brun,
André d'Entremont

July, 2001
Report 031

Maintaining Ecological Integrity of our Parks • Maintenir l'intégrité écologique de nos parcs

Atlantic Region, Parks Canada is producing three report series in ecosystem science. They are intended to communicate new scientific information, document scientific data, summarize existing knowledge, or offer technical recommendations. The primary function and the intended audience of a report determine the series in which it will be published. Each report series contains scientific and technical information that contributes to existing knowledge but is not in a form suitable for the primary journal literature.

- ***Parks Canada-Technical Reports in Ecosystem Science*** promote a wide distribution of scientific and technical information from Parks Canada's ecosystem investigations. The subject matter, and the series reflect the broad interest and policies of Parks Canada in ecosystem science. This series includes such work as, ecosystem and resource inventories, studies, surveys of species or guilds, and innovative management concepts.
- ***Parks Canada - Ecosystem Science Review Reports*** provides a forum for literature reviews, bibliographies, and reviews of management options that are often prepared for or by Parks Canada. Resource Descriptions and Analyses or chapters thereof will be published in this series.
- ***Parks Canada - Ecosystem Monitoring and Data Reports*** provide a medium for filing and achieving data compilations where little or no analysis is included. Such compilations commonly are prepared in support of primary publications or Technical Reports in Ecosystem Science. Raw data not available in a national data base and considered worth archiving is published as a Parks Canada - Ecosystem Monitoring and Data Report.

Ecosystem Science Reports are printed in the official language chosen by the author to meet the language preference of the likely audience, with an abstract in the second official language.

Objectives

Our objectives for these report series are;

- To communicate the results of ecosystem science research to the scientific and management communities, and to the public interested in Parks Canada environmental and conservation activities;
- To provide credible, accurate, and professional publications through a peer review process,
- To encourage creativity, effectiveness, and teamwork in conducting research and in providing information through publications.

Peer Review

The editor appoints two referees to critically review each manuscript. Referees are found, if possible, from scientific staff within Parks Canada. Due to areas of expertise, available time, and to avoid the potential of 'inbreeding' external reviewers will often be sought. Referees review the manuscript and return it to the editor with their written comments. The editor then returns the paper to the author(s) with the referee's comments. The author(s) consider(s) the referees' comments and incorporates those that they accept, into the report. The author(s) return(s) the revised manuscript to the editor and/or provides a written rationale for any exclusions of the referees' comments considered unacceptable. The editor then sends the revised manuscript to the Chief Park Warden or for the case of Regional Office staff to the author(s) direct supervisor for approval to publish and printing. At the editor's discretion, the appointment of referees may be dispensed with, if the publication is minor in nature. In such instances, the editor and the author's direct supervisor would assume the roles of the referees. In the unlikely event that an author and editor are in disagreement over a manuscript, the matter will be refereed to a Senior Departmental Manager for adjudication.

Directives for Authors

These series are intended for the publication of work in ecosystem science that is conducted in the Atlantic Region. They are available for use by any Parks Canada or Department of Canadian Heritage staff or others working in collaboration with, or on a contract to, the Department of Canadian Heritage.

The author(s) submits one paper copy of the completed draft of their paper and a digital version on a diskette in WordPerfect Windows or DOS format to the regional editor along with three suggested referees. Suggested referees should not have been previously involved with the manuscript.

Detailed instructions to authors can be obtained from:

Neil Munro
Report Series Editor

Parks Canada
Historic Properties
Halifax, Nova Scotia
B3J 1S9

(902) 426-2797
(FAX) 426-2728

101-06653/

Parks Canada - Technical Reports in Ecosystem Science

Report 031

Mercury Concentrations in Yellow Perch (*Perca flavescens*)

from 24 Lakes at Kejimkujik National Park, Nova Scotia

by

Jennifer Carter [1], Clifford Drysdale [2], Neil Burgess [3], Stephen Beauchamp [4], Guy Brun [5], André d'Entremont [6]

July, 2001

[1] Carter Environmental Consulting, Halifax, NS (currently Toronto, ON)

[2] Parks Canada, Kejimkujik National Park, Maitland Bridge, NS

[3] Environment Canada, Wildlife Conservation, St. John's, NF

[4] Environment Canada, Atmospheric Science, Dartmouth, NS

[5] Environment Canada, Ecosystem Science, Moncton, NB

[6] Parks Canada, Halifax, NS (currently Canada-Nova Scotia Offshore Petroleum Board, Halifax, NS)

Canadian Cataloguing in Publication Data

Carter, Jennifer 1970-

Mercury Concentrations in Yellow Perch (Perca flavescens) from 24 Lakes at Kejimkujik National Park, Nova Scotia

(Parks Canada – Technical reports in ecosystem science; no. 31)
Includes an abstract in French.
Includes bibliographical references.

ISSN 1200-3298; report no. 31
ISBN 0-662-29914-0
Catalogue No. R61-2/19-31-2001E

1. Mercury – Environmental aspects – Nova Scotia – Kejimkujik National Park.
2. Yellow perch – Effect of water pollution on – Nova Scotia – Kejimkujik National Park.
I. Carter, Jennifer A.
II. Parks Canada. Atlantic Region.
III. Series: Technical reports in ecosystem science; no. 31.

TD196.M38M38 2001 363.738'4 C2001-980030-4

Published by authority of the Minister of Canadian Heritage
© Her Majesty the Queen in Right of Canada, represented by the Chief Executive Officer of Parks Canada, 2001

Contents

List of Figures ... iv
List of Tables ... iv
Abstract ... v
Résumé ... v
Acknowledgements ... vi
1.0 Introduction ... 1
2.0 Study Methodology ... 2
2.1 Study Site ... 2
2.2 Field Procedures ... 2
2.3 Analytical Procedures ... 4
2.4 Statistical Procedures ... 4
3.0 Results ... 5
4.0 Discussion ... 14
References ... 22

Figures

Figure 1. Location of Kejimkujik National Park in Atlantic Canada ... 2

Figure 2. Locations of yellow perch sampling sites at Kejimkujik National Park ... 3

Figure 3. Relationships between total mercury concentration and fish age, length and weight in yellow perch from 24 lakes at Kejimkujik ... 7

Figure 4. Regression lines for mercury accumulation in yellow perch from 24 lakes at Kejimkujik ... 8

Figure 5. Mean mercury concentrations for length-corrected yellow perch from 24 lakes at Kejimkujik ... 10

Figure 6. Mean mercury concentrations for length-corrected yellow perch from six watersheds at Kejimkujik ... 10

Figure 7. Relationships between mercury concentrations in yellow perch and acidity, TOC, mercury and aluminum concentrations in lake water ... 13

Tables

Table 1. Total mercury concentrations and fork length, weight and age of composite yellow perch samples from 24 lakes ... 6

Table 2. Mercury concentrations for size-corrected yellow perch, lake surface area and maximum depth, and lake water chemistry for 24 lakes ... 9

Table 3. Mean concentrations of chemical parameters for water samples collected from 24 lakes at Kejimkujik ... 11

Table 4. Significant correlations ($p<0.05$) among perch Hg concentrations and water chemistry parameters ... 12

Table 5. Comparison yellow perch mercury concentrations in different studies ... 15

Abstract

As part of a larger study on the bioaccumulation and ecological effects of mercury in freshwater fish and wildlife in Atlantic Canada, we measured total mercury in yellow perch (*Perca flavescens*) from 24 lakes in Kejimkujik National Park, Nova Scotia. The objectives of the study were to assess mercury concentrations in prey of common loons (*Gavia immer*), which themselves have high mercury levels, and to determine which environmental factors were associated with differences in fish mercury concentrations from lake to lake. The mean perch mercury concentration was 0.25 μg/g, with a range of 0.05-0.77 μg/g, in 242 composite fish samples. These values are similar to those found in several other yellow perch studies in Atlantic Canada and eastern North America. Fish length, weight, and age, averaging 12.0cm, 26.1g, and 5.1 years, respectively, were significantly correlated ($r > 0.7$, $p < 0.0001$) with whole fish mercury concentrations. Significant differences were found between lakes in rates of mercury accumulation with fish length ($p < 0.05$). Size-adjusted mean fish mercury concentrations correlated negatively with lake water alkalinity ($r = -0.62$) and pH ($r = -0.58$) and positively with water aluminum ($r = 0.52$), total organic carbon ($r = 0.54$), mercury ($r = 0.52$) and iron ($r = 0.48$) concentrations. Significant differences in size-adjusted perch mercury concentrations when the lakes were grouped by watershed were correlated with the following water chemistry parameters: total organic carbon ($p=0.02$), colour ($p = 0.04$), pH ($p = 0.02$) and alkalinity ($p = 0.007$).

Résumé

Dans le cadre d'une étude plus vaste sur la bioaccumulation du mercure et ses effets écologiques sur le poisson d'eau douce et la faune au Canada atlantique, nous avons mesuré l'accumulation totale de mercure dans la perchaude (*Perca flavescens*) de 24 lacs au parc national Kejimkujik, en Nouvelle-Écosse. L'étude avait pour but d'évaluer les concentrations de mercure dans les proies du plongeon huard (*Gavia immer*), qui présente lui-même des niveaux de mercure élevés, et de déterminer quels étaient les facteurs environnementaux à l'origine des concentrations de mercure dans le poisson d'un lac à l'autre. La concentration moyenne de mercure dans la perchaude était de 0,25 μg/g, avec une fourchette de 0,05 à 0,77 μg/g, dans 242 échantillons composites de poisson. Ces valeurs sont semblables à celles trouvées dans le cadre de plusieurs autres études sur la perchaude au Canada atlantique et dans l'est de l'Amérique du Nord. Il existe une corrélation significative ($r > 0,7$, $p < 0,0001$) entre la longueur, le poids et l'âge du poisson, en moyenne 12 cm, 26,1 g et 5,1 ans respectivement, et les concentrations de mercure qu'on y trouve. On a trouvé des différences significatives d'un lac à l'autre dans les taux d'accumulation du mercure par rapport à la longueur du poisson ($p < 0,05$). Les concentrations moyennes de mercure dans le poisson rajustées en fonction de la taille ont montré des corrélations négatives avec des facteurs tels que l'alcalinité de l'eau du lac ($r = -0,62$) et son pH ($r = -0,58$), et des corrélations positives avec les concentrations dans l'eau d'aluminium ($r = 0,52$), de carbone organique total ($r = 0,4$), de mercure ($r = 0,52$) et de fer ($r = 0,48$). Des corrélations avec les paramètres chimiques suivants de l'eau ont permis de constater des différences considérables des concentrations de mercure dans la perche rajustées en fonction de la taille lorsque les lacs sont regroupés par bassin hydrographique : carbone organique totale ($p = 0,02$), coloration ($p = 0,04$), pH ($p = 0,02$) et alcalinité ($p = 0,007$).

Acknowledgements

The authors gratefully acknowledge the help of Robert Nicholas and Gary Corbett, who coordinated sample collection, and Sean Hope Cheryl Frail and John Drysdale (volunteer) who assisted with collection and sample preparation. Gary Corbett's helpful comments on the manuscript were very much appreciated. Thanks also to Sally O'Grady who provided valuable mapping and other data on the Kejimkujik lakes.

1.0 INTRODUCTION

Elevated concentrations of mercury in aquatic biota have historically been attributed to nearby anthropogenic point sources such as local industrial discharges. However, in recent years, considerable attention has been paid to the long-range transport and fate of mercury (Hg) in the environment, as studies in remote regions around the world have found Hg concentrations comparable to those in areas close to known pollution sources (Driscoll et al. 1994, Stafford & Haines 1997, Haines et al. 1995). Kejimkujik National Park, a relatively pristine and remote wilderness area in southwestern Nova Scotia (Fig. 1), is no exception. In 1996, Burgess et al. reported high Hg concentrations in the blood of common loons (*Gavia immer*) breeding on Kejimkujik lakes. These concentrations were twice as high as those found in loon populations elsewhere in North America, including regions such as the northwestern United States, the upper Great Lakes and New England (Evers et al. 1998).

The elevated Hg concentrations in Kejimkujik loons raised broader concerns about atmospheric deposition of mercury and biomagnification in local aquatic food webs. This prompted researchers from Parks Canada, Environment Canada, Dalhousie University (Halifax, NS), and other agencies and universities to coordinate their efforts to determine the concentrations, sources and pathways of Hg within air, water, sediments, fish, fish-eating wildlife and other biota in Atlantic Canada. Many of the studies are focused on, or include, Kejimikujik because of the park's relatively undeveloped environment remote from local pollution sources, its numerous lakes, and the wealth of environmental quality data that already exists for the site. Additional research is being conducted in the provinces of New Brunswick and Newfoundland, and other areas of Nova Scotia (Burgess et al. 1998a).

Mercury-contaminated fish comprise the major route for transfer of Hg from the aquatic environment to fish-eating birds and mammals, including humans (Rodgers 1994). Fish bioacummulate Hg very efficiently, at a rate that varies according to a complex set of factors including diet and water chemistry. Thus, the objectives of this study were to measure the Hg concentrations in fish from numerous lakes at Kejimkujik National Park, and to determine which lake chemistry and watershed characteristics are associated with mean fish Hg concentrations from lake to lake. Yellow perch (*Perca flavescens*) were selected as the study species because they form a major component of the loon diet (Barr 1996) and are plentiful in the mainly acidic and brown-water lakes of the park. The potential human health concerns from the consumption of larger sports fish at Kejimikujik have been addressed by d'Entremont et al. (1998), in a report on mercury concentrations in brook trout (*Salvelinus fontinalis*) and white perch (*Morone americana*) fillets.

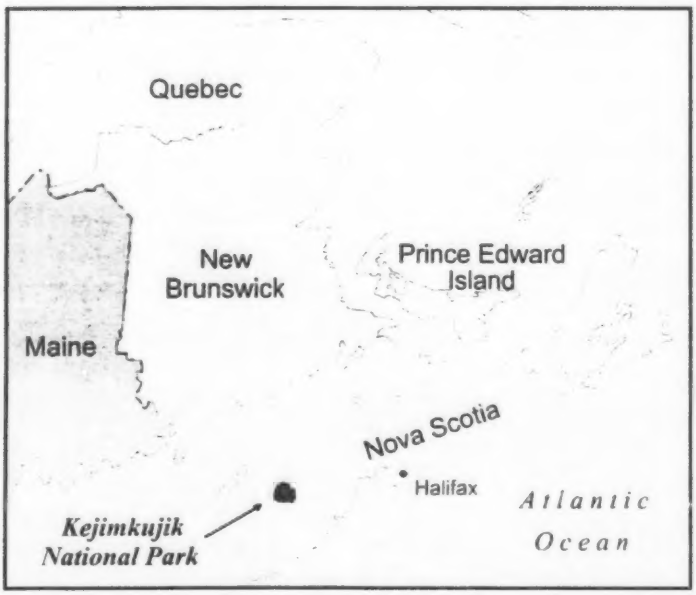

Figure 1. Location of Kejimkujik National Park in Atlantic Canada

2.0 STUDY METHODOLOGY

2.1 Study Site

Kejimkujik National Park, Nova Scotia, Canada (44°20'N, 65°20'W) (Fig. 1) contains 46 oligotrophic lakes, many of which are naturally acidic with high dissolved organic carbon, low calcium concentrations and low alkalinity. Twenty-four lakes, all of which are used by common loons for feeding or breeding, were chosen for this study (Fig. 2). The lakes were also selected to represent the major geological features within the park.

2.2 Field Procedures

Yellow perch were collected from a single site in each of the following 21 lakes: Back, Big Dam East, Big Dam West, Beaverskin, Big Red, Channel, Cobrielle, Frozen Ocean, George, Hilchemakaar, Liberty, Loon, Luxton, Lower Silver, Mountain, North Cranberry, Pebbleloggitch, Poplar, Peskowesk, Puzzle, and Upper Silver (Fig. 2). Perch were also collected at three different sites within each of three additional larger lakes, Grafton, Kejimkujik and Peskawa (Fig. 2), to allow us to assess intra-lake variation of perch mercury levels. From each of the 30 sites, the goal was to collect 27 yellow perch: nine from each of three size classes (5-10, 10-15, and 15-20 cm fork length). A total of 677 fish were captured using minnow traps, trap nets, electroshocker, and by angling during July and August, 1996

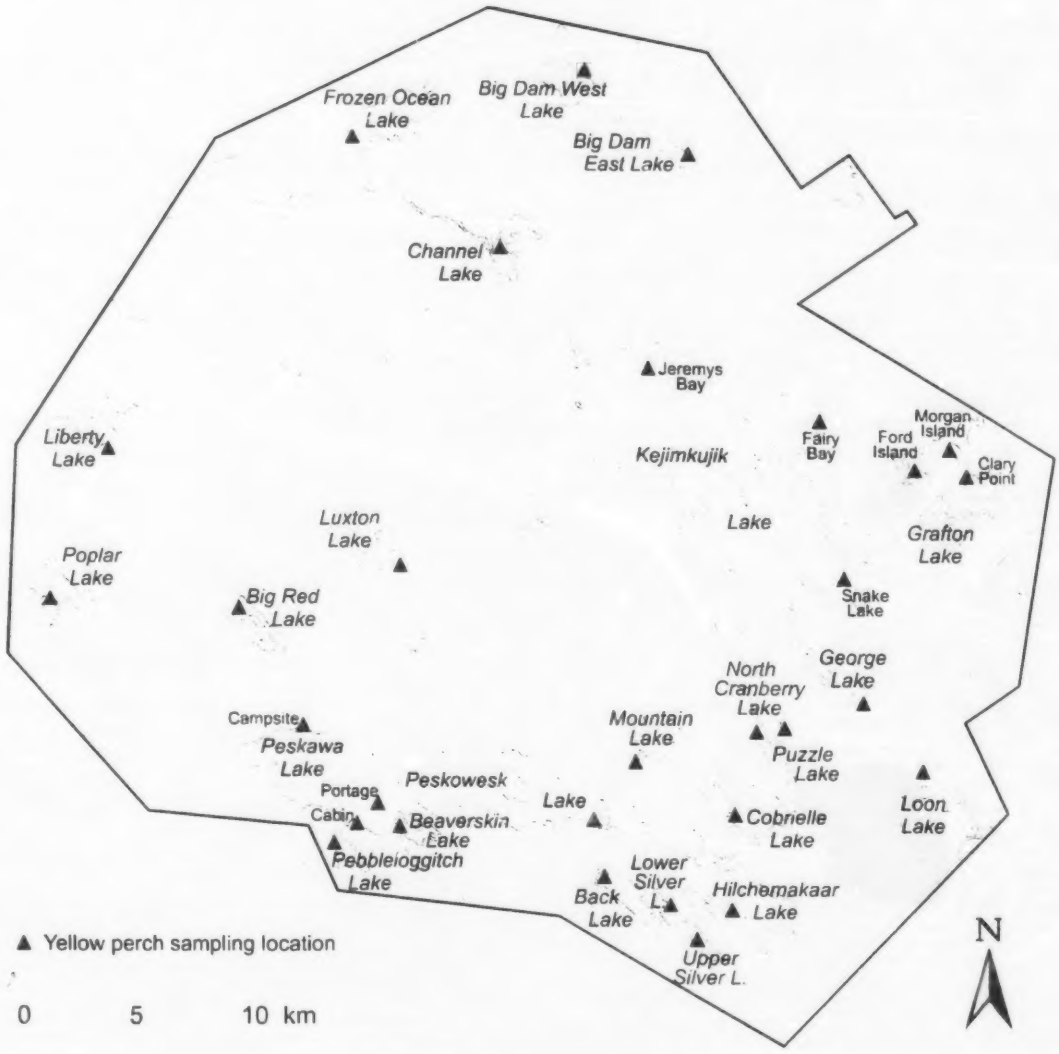

Figure 2. Locations of yellow perch sampling sites at Kejimkujik National Park

and 1997. Fish weight and fork length were measured at capture, and later aged using scale samples. Whole fish were wrapped in plastic wrap, individually placed in plastic bags and stored in a cooler. They were frozen within 24 hours and shipped to the Environment Canada Atlantic Region Laboratory, Moncton, New Brunswick.

Lake water samples were collected in the spring (May-June) and/or fall (October) of 1995, 1996 and 1997, with the exception of Puzzle, North Cranberry, Lower Silver and Hilchemakaar Lakes, where samples were only taken in 1996 and 1997. Samples were collected at a depth of one metre and immediately placed on ice, refrigerated within 48 hours and shipped to the Environment Canada laboratory.

2.3 Analytical Procedures

Frozen fish were homogenized whole, following the Environment Canada (1982) procedure. Composite samples for mercury analysis were composed of the pooled homogenate of (usually) three perch of similar length from the same collection site. The 242 samples were analyzed for total Hg according to standard Environment Canada (1982) procedures. Organomercury compounds in the samples were oxidized to inorganic mercury by sulfuric acid, dichromate and UV photooxidation. After oxidation, the mercuric ions were reduced with stannous sulfate (10% w/v) in hydroxylamine sulfate-sodium chloride solution (12% w/v) to elemental mercury. Total mercury content was then measured using cold vapor atomic absorption spectrometry (CVAAS). All fish Hg concentrations were reported on a wet-weight basis. Quality assurance/quality control (QA/QC) procedures included analyses of method blanks, sample replicates, spiked tissues and fish tissue standard reference materials.

2.4 Statistical Procedures

For each composite fish sample analyzed for total mercury, an average fish fork length, weight and age was calculated, using averages weighted by the individual fish weights. Mercury concentrations in fish were Log10-transformed prior to some linear regression and analysis of covariance (ANCOVA) calculations. To allow a comparison with lake chemistry parameters, mean size-adjusted perch mercury concentrations were calculated for a standard length of 12 cm (the average fork length for the entire sample set). Relationships between variables were assessed by Pearson correlations. All statistical analyses were conducted using STATGRAPHICS® Plus for Windows software, version 3 (Manugistics Inc., Rockville, Maryland, 1997) or Systat® for Windows software, version 7.0 (SPSS Inc., Chicago Illinois, 1997).

3.0 RESULTS

Total Hg concentrations in the 242 composite yellow perch samples ranged from 0.05 to 0.77 μg/g, with an overall mean concentration (± SD) of 0.25 ± 0.14 μg/g (Table 1). The composite samples had average fork lengths of 5.8 to 20.0 cm, weights of 1.9 to 105 g, and ages of 1 to 10 years. Overall means for fork length, weight and age were 12.0 cm, 26.1 g, and 5.1 years, respectively (Table 1). Significant positive correlations ($p<0.00001$) were found between log10-transformed Hg concentrations and fish age ($r=0.76$), fork length ($r=0.74$) and weight ($r=0.70$) (Fig. 3).

For the three lakes sampled in three different locations to assess intra-lake variability, the mean perch Hg concentrations were 0.20, 0.24 and 0.26 μg/g in Grafton Lake; 0.26, 0.28 and 0.31 μg/g in Kejimkujik Lake; and 0.19, 0.21 and 0.29 μg/g in Peskawa Lake. ANCOVA analysis of the data, using fork length as the covariate and log10 Hg as the dependent variable, demonstrated that there were no significant differences among the three sites in each lake ($p>0.05$). Therefore, for all further analyses, results from the three sites in each lake were grouped together to give overall mean Hg concentrations and length, weight and age measurements.

Average perch Hg concentrations at Kejimkujik ranged from a low of 0.13 ± 0.06 μg/g in Back Lake to a high of 0.46 ± 0.16 μg/g in Big Red Lake. ANCOVA analyses demonstrated that, after adjusting for differences in fish length, significant differences in fish Hg concentration existed between the lakes ($p<0.00001$). This was accompanied by significantly different growth rates in the lakes ($p<0.00001$), using both increases in fork length with age and weight with age as measures of growth. However, when differences in log10 Hg concentrations between the lakes were further examined by ANCOVA, only increases in length with age significantly explained the different rates of Hg accumulation ($p=0.026$). Figure 4 shows the regression lines for Hg accumulation with length for the 24 lakes.

The mean adjusted perch Hg concentrations for a standard fish length of 12 cm, calculated to allow comparison with lake chemistry parameters, are shown in Table 2 and Figure 5. There was a significant difference ($p<0.001$) in mean size-adjusted Hg concentrations when lakes were grouped according to the watershed they are located in (Figs. 5, 6). The five study lakes in the Shelburne watershed had an average fish Hg of 0.16 μg/g (which is significantly different from the other five watersheds), while the three West River watershed lakes had an average fish Hg of 0.37 μg/g , again significally different from the other five watersheds. The Little River, Mersey River, Minard Brook and Peskowesk Brook watersheds had similar mean perch Hg concentrations, ranging from 0.23 to 0.29 μg/g. There were no correlations between fish Hg concentrations and lake area/maximum depth or watershed area.

Table 1. Total mercury concentrations and fork length, weight and age of composite yellow perch samples from 24 lakes at Kejimkujik National Park.

Lake (location)	# Samples		Length	Weight	Age	Total Hg		
	Fish	Pooled	(cm)	(g)	(years)	(ug/g)	SD	Range
Back	22	9	12.7	30.3	5.06	0.13	0.06	0.06-0.26
Beaverskin	27	10	11.6	20.6	3.73	0.19	0.08	0.08-0.35
Big Dam East	23	8	11.4	21.3	4.77	0.18	0.08	0.07-0.33
Big Dam West	21	7	10.8	21.4	5.48	0.21	0.10	0.08-0.31
Big Red	26	9	12.2	26.3	6.35	0.46	0.16	0.22-0.76
Channel	19	7	10.4	17.3	5.73	0.21	0.10	0.08-0.38
Cobrielle	18	6	14.6	39.3	5.03	0.26	0.07	0.20-0.39
Frozen Ocean	26	9	12.1	32.7	5.73	0.26	0.16	0.06-0.58
George	25	10	12.6	28.1	5.50	0.29	0.19	0.09-0.69
Hilchemakaar	26	9	12.6	31.6	5.19	0.26	0.21	0.10-0.77
Liberty	27	9	12.5	26.8	4.49	0.29	0.08	0.20-0.40
Loon	26	9	13.1	33.2	5.90	0.27	0.11	0.14-0.50
Lower Silver	27	9	12.4	27.0	4.43	0.18	0.04	0.12-0.26
Luxton	26	9	12.5	31.2	5.65	0.39	0.18	0.21-0.75
Mountain	23	8	12.1	28.1	5.14	0.22	0.12	0.09-0.47
North Cranberry	27	9	12.6	26.4	5.59	0.37	0.14	0.21-0.63
Pebblelogitch	27	9	12.4	30.3	5.04	0.16	0.04	0.09-0.20
Peskowesk	23	8	12.4	29.6	5.05	0.28	0.16	0.16-0.64
Poplar	26	9	13.1	35.7	5.97	0.34	0.15	0.17-0.65
Puzzle	23	8	11.5	22.0	4.85	0.23	0.10	0.10-0.40
Upper Silver	19	7	10.7	17.5	3.78	0.14	0.06	0.05-0.23
Grafton Clary Pt	21	8	12.4	26.6	4.79	0.26	0.11	0.13-0.46
Ford Island	15	6	12.8	24.7	4.97	0.24	0.12	0.11-0.39
Morgan Island	21	7	10.7	20.4	4.27	0.20	0.11	0.09-0.41
Grafton Total	*57*	*21*	*11.9*	*24.0*	*4.67*	*0.23*	*0.11*	*0.09-0.46*
Kejimkujik Fairy Bay	18	7	10.9	18.2	4.62	0.26	0.10	0.11-0.42
Jeremys Bay	22	8	11.7	24.6	5.33	0.31	0.10	0.14-0.40
Snake Island	23	8	11.4	22.0	5.68	0.28	0.12	0.11-0.50
Kejimkujik Total	*63*	*23*	*11.3*	*21.8*	*5.23*	*0.28*	*0.10*	*0.11-0.50*
Peskawa Cabin	16	6	10.0	14.1	4.02	0.19	0.07	0.11-0.30
Campground	16	6	9.3	10.1	3.98	0.21	0.06	0.13-0.28
Portage	18	8	12.7	33.2	5.20	0.29	0.18	0.11-0.56
Peskawa Total	*50*	*20*	*10.9*	*20.6*	*4.48*	*0.24*	*0.13*	*0.11-0.56*
Totals	**677**	**242**	**12.0**	**26.1**	**5.08**	**0.25**	**0.14**	**0.05-0.77**

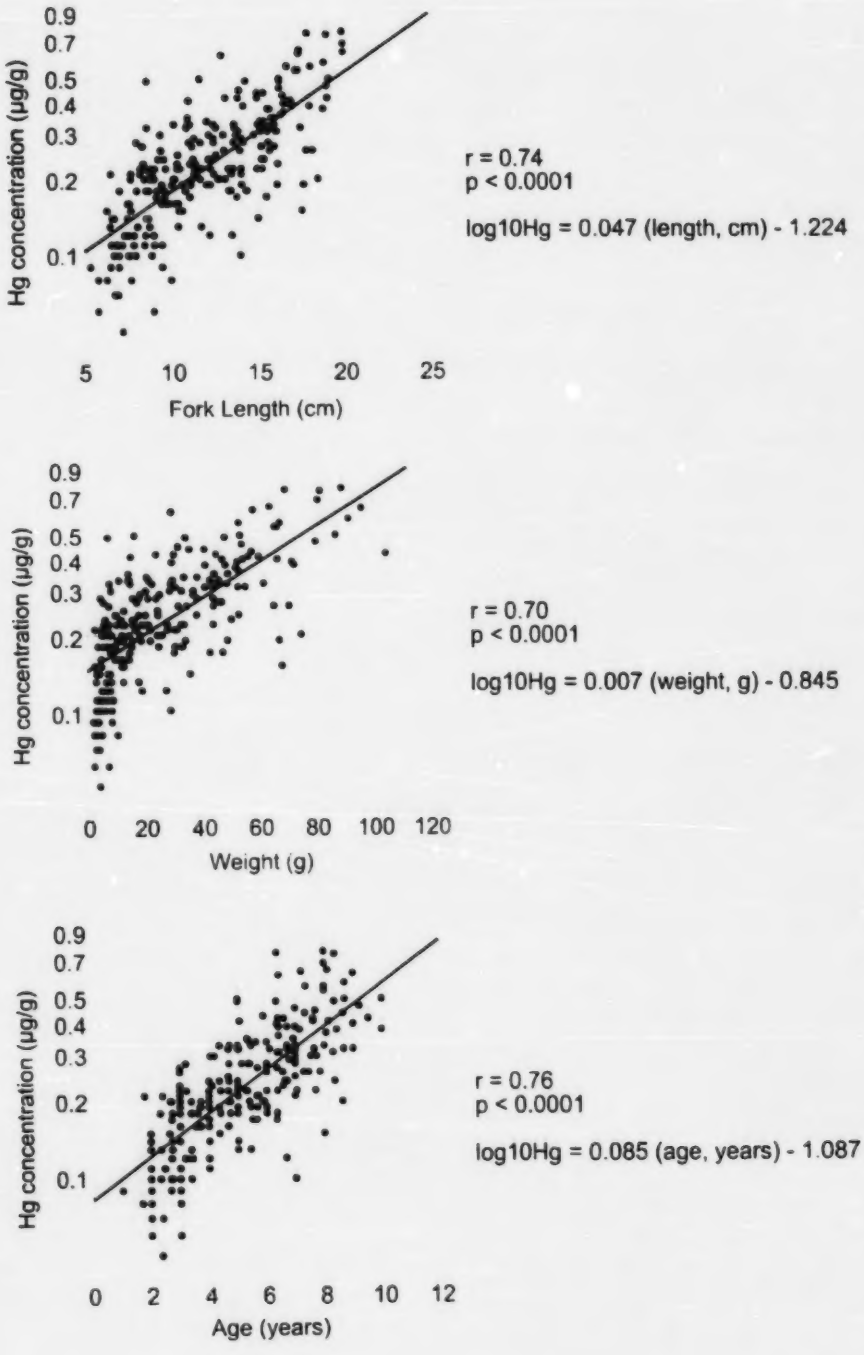

Figure 3. Relationships between total mercury concentration and fish age, length and weight in yellow perch from 24 lakes at Kejimkujik

Several lake water chemistry parameters (Tables 2, 3) were significantly correlated ($p<0.05$) with differences in perch Hg concentrations. Correlation coefficients and probabilities are summarized in Table 4, and some regression graphs are shown in Figure 7. Positive and negative correlations with fish Hg concentrations include alkalinity ($r = -0.62$), pH ($r = -0.58$), aluminum concentration ($r = 0.52$), total organic carbon (TOC, $r = 0.54$), and water Hg ($r = 0.52$) and iron ($r = 0.48$) concentrations. Water Hg was highly correlated ($p<0.001$) with TOC and specific conductivity ($r > 0.90$) and with pH ($r = 0.69$). Aluminum and iron were also significantly correlated with TOC. As would be expected, TOC and water colour were very highly correlated ($r>0.98$), so all variables correlated with TOC also correlated with colour. ANCOVA analysis on the lake chemistry data grouped according to watershed demonstrated that TOC ($p=0.02$) and pH ($p=0.02$) were significant in explaining the differences between Hg concentrations of length-adjusted fish from one watershed to another.

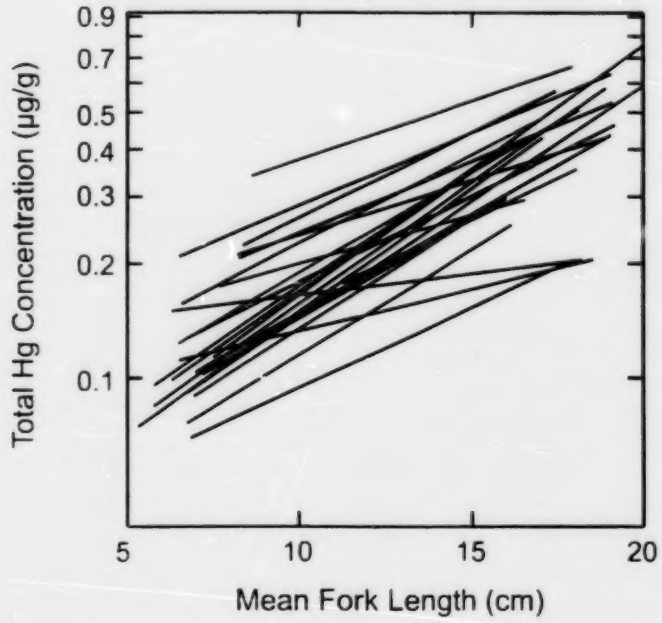

Figure 4. Regression lines for mercury accumulation in yellow perch from 24 lakes at Kejimkujik

Table 2. Mercury concentrations for size-corrected yellow perch, lake surface area and maximum depth, and lake water chemistry for 24 lakes at Kejimkujik.

Lake	Area	Max Depth	12 cm Fish Hg	# Water Samples		pH	Gran Alkalinity	Color	TOC	Spec. Cond.
	(Ha)	(m)	(µg/g)	Spr.	Fall	(units)	(mg/l)	(Hazen)	(mg/l)	µS/cm
Back	78.4	5.75	0.13	3	4	5.31	0.24	27.9	4.06	21.7
Beaverskin	39.5	6.25	0.20	3	3	5.27	-0.06	11.7	2.55	21.8
Big Dam East	45.5	4.20	0.19	3	4	5.90	0.92	20.7	3.73	23.8
Big Dam West	105.0	9.50	0.24	3	4	5.00	0.07	93.6	10.53	30.1
Big Red	70.5	2.20	0.46	3	4	4.29	-2.54	155.0	17.01	38.5
Channel	86.5	na	0.25	3	3	4.73	-0.53	106.7	12.18	29.0
Cobrielle	132.0	6.25	0.19	3	4	5.33	0.08	27.5	3.93	21.8
Frozen Ocean	228.0	7.60	0.26	3	4	4.83	-0.27	97.1	10.67	29.0
George	77.8	8.50	0.27	3	3	5.03	-0.21	62.5	7.00	27.9
Grafton	270.0	10.00	0.23	3	4	5.80	1.12	47.1	6.06	32.0
Hilchemakaar	95.4	7.25	0.24	1	5	5.42	0.70	52.5	5.68	25.5
Kejimkujik	2435.0	19.20	0.30	3	5	5.03	-0.03	71.9	7.86	28.1
Liberty	73.3	na	0.28	3	4	5.27	0.02	30.7	4.53	22.9
Loon	73.8	8.50	0.23	3	6	5.08	-0.02	63.3	6.91	27.9
Lower Silver	24.7	5.25	0.18	1	3	5.65	0.74	19.4	3.28	20.9
Luxton	47.1	8.50	0.37	5	4	4.74	-0.69	51.1	7.50	26.5
Mountain	136.0	14.25	0.21	3	4	5.36	0.18	25.0	3.70	21.5
North Cranberry	34.3	5.00	0.34	2	3	5.14	-0.12	29.0	4.52	21.1
Pebblelogitch	33.4	5.00	0.15	3	4	4.53	-1.27	101.3	11.20	30.1
Peskawa	388.0	9.00	0.26	3	4	4.67	-0.77	60.7	7.37	26.9
Peskowesk	685.0	13.00	0.26	3	5	4.84	-0.60	38.8	5.48	24.7
Poplar	82.5	na	0.31	3	4	4.80	-0.52	51.4	6.80	26.5
Puzzle	33.7	6.10	0.24	0	2	5.30	0.02	17.5	3.30	20.5
Upper Silver	24.3	5.75	0.16	3	4	5.91	0.85	18.2	3.27	21.7

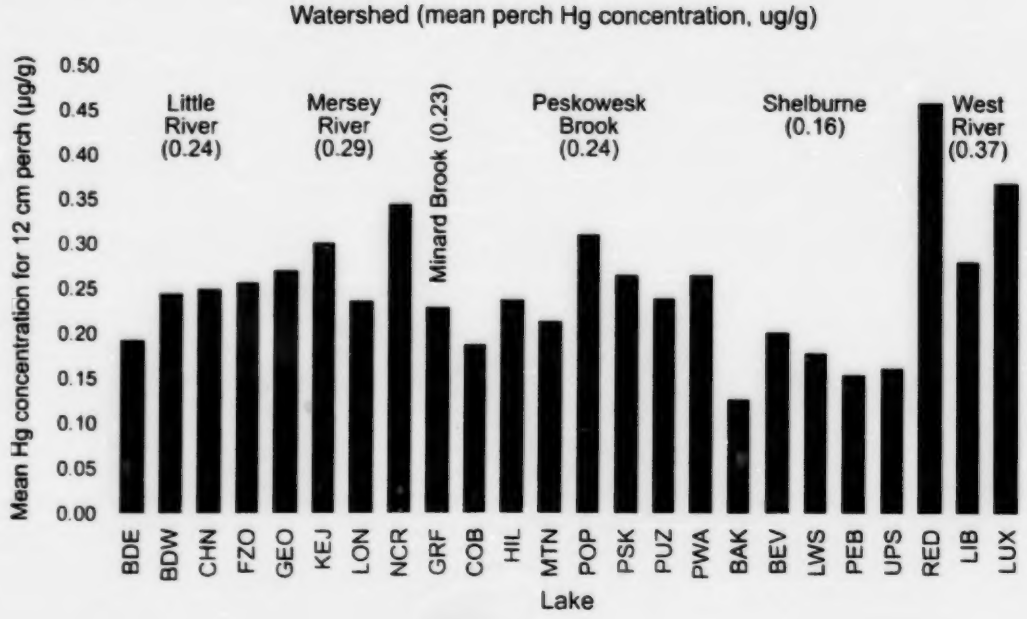

Figure 5. Mean mercury concentrations for length-corrected yellow perch from 24 lakes at Kejimkujik

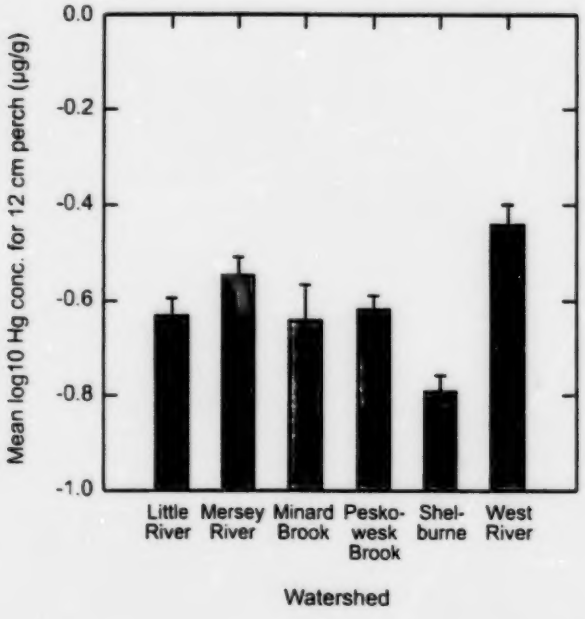

Figure 6. Mean mercury concentrations for length-corrected yellow perch from six watersheds at Kejimkujik

Table 3. Mean concentrations of chemical parameters for water samples collected from 24 lakes at Kejimkujik

Lake	12 cm. Fish Hg	Cl	SO_4	total N_2	Na	K	Ca	Mg	Al	Fe	Mn	Hg
	(µg/g)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(mg/l)	(ng/l)
Back	0.13	3.56	1.86	0.08	2.46	0.28	0.45	0.31	0.08	0.06	0.020	2.44
Beaverskin	0.20	3.75	1.91	0.06	2.63	0.22	0.30	0.31	0.04	0.01	0.013	1.54
Big Dam East	0.19	4.06	1.80	0.07	2.93	0.21	0.61	0.38	0.07	0.04	0.013	2.78
Big Dam West	0.24	4.84	1.69	0.11	3.52	0.31	0.64	0.36	0.20	0.17	0.015	5.01
Big Red	0.46	3.61	1.77	0.13	2.72	0.32	0.26	0.30	0.21	0.17	0.007	7.40
Channel	0.25	3.85	1.53	0.11	2.90	0.27	0.52	0.34	0.20	0.19	0.018	5.03
Cobrielle	0.19	3.61	1.78	0.08	2.55	0.20	0.35	0.30	0.10	0.08	0.024	2.60
Frozen Ocean	0.26	4.26	1.68	0.11	3.15	0.29	0.54	0.35	0.19	0.18	0.015	4.80
George	0.27	4.45	2.00	0.08	3.14	0.26	0.59	0.36	0.13	0.16	0.030	4.19
Grafton	0.23	5.62	2.26	0.12	3.89	0.22	0.95	0.49	0.08	0.26	0.108	4.28
Hilchemakaar	0.24	3.67	2.07	0.10	2.69	0.22	0.77	0.38	0.09	0.12	0.018	3.18
Kejimkujik	0.30	4.45	1.93	0.09	3.14	0.30	0.62	0.37	0.16	0.20	0.031	3.54
Liberty	0.28	3.88	1.81	0.08	2.75	0.25	0.34	0.31	0.15	0.14	0.017	2.85
Loon	0.23	4.60	2.05	0.08	3.19	0.28	0.62	0.38	0.15	0.17	0.029	3.87
Lower Silver	0.18	3.61	1.72	0.10	2.50	0.33	0.52	0.30	0.05	0.04	0.013	1.53
Luxton	0.37	3.57	2.03	0.09	2.67	0.27	0.26	0.29	0.27	0.22	0.008	4.54
Mountain	0.21	3.51	1.73	0.07	2.49	0.21	0.42	0.29	0.12	0.08	0.027	1.78
North Cranberry	0.34	3.27	1.74	0.10	2.34	0.18	0.42	0.29	0.08	0.07	0.010	1.93
Pebblelogitch	0.15	3.46	1.87	0.12	2.54	0.22	0.30	0.29	0.21	0.16	0.005	5.32
Peskawa	0.26	3.62	1.93	0.10	2.67	0.26	0.27	0.28	0.24	0.18	0.014	3.80
Peskowesk	0.26	3.65	1.97	0.10	2.60	0.25	0.31	0.28	0.22	0.13	0.019	2.74
Poplar	0.31	3.79	2.07	0.08	2.75	0.25	0.33	0.31	0.20	0.17	0.008	4.75
Puzzle	0.24	3.38	1.62	0.09	2.32	0.26	0.35	0.29	0.05	0.09	0.015	0.87
Upper Silver	0.16	3.62	1.92	0.07	2.57	0.29	0.61	0.31	0.06	0.02	0.005	1.83

Table 4. Significant correlations ($p<0.05$) among perch Hg concentrations and water chemistry parameters

Parmeter 1	Parameter 2	Pearson Correlation Coefficient	Probability
Perch Hg conc.	pH	-0.58	0.003
	Alkalinity	-0.62	0.001
	Aluminum	0.52	0.009
	Iron	0.48	0.017
	TOC	0.54	0.007
	Water Hg conc.	0.52	0.009
Water Hg conc.	TOC	0.90	<0.00001
	Specific conductivity	0.94	<0.00001
	pH	0.69	<0.001
Aluminum	TOC	0.70	<0.001
Iron	TOC	0.64	<0.001
TOC	Water colour	0.99	<0.00001

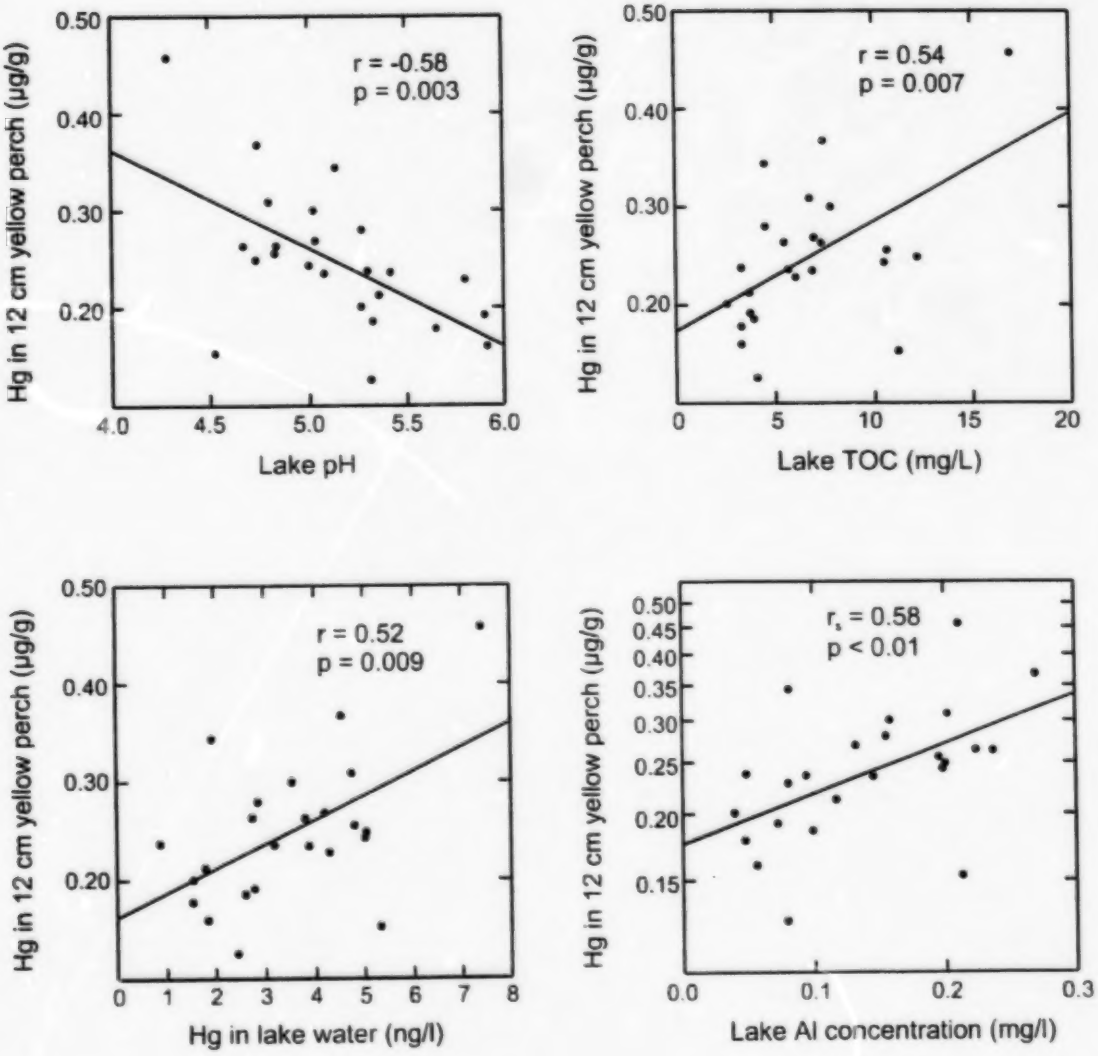

Figure 7. Relationships between mercury concentrations in yellow perch and acidity, TOC, mercury and aluminum concentrations in lake water

4.0 DISCUSSION

The mean Hg concentration of 0.25 ± 0.14 µg/g for whole yellow perch reported here is similar to those found in other studies of waterbodies in Nova Scotia and eastern North America. These results are summarized in Table 5. In Nova Scotia, composite yellow perch samples (mean length 12.2 cm) from five lakes east of Halifax, and therefore east of Kejimkujik, had mean Hg concentrations of 0.20-0.31 µg/g, with an overall average of 0.26 ± 0.08 µg/g (Rutherford et al. 1998 and L. Rutherford pers. comm.). In 1990, Peterson et al. reported the following average Hg concentrations for yellow perch with a mean length of 15.6 cm: 0.11 µg/g for 56 lakes in southwest Nova Scotia and 0.56 µg/g for fourteen lakes east of Halifax. The same studies indicated yellow perch from lakes in New Brunswick have lower Hg concentrations: 0.14 ± 0.09 µg/g in fish with a mean length of 13.5 cm from thirteen lakes (Rutherford et al. 1998), and 0.018 µg/g in fish with a mean length of 15.9 cm from 63 lakes (Peterson et al. 1990). An ongoing study, however, is showing a much higher mean Hg concentration of 0.36 µg/g in pooled samples of yellow perch, with a mean fork length of 17.7 cm, from six lakes in southwestern New Brunswick (E. Barry, pers. comm.).

Several other studies have measured Hg concentrations in yellow perch fillets rather than whole fish. For the purpose of comparison, it will be assumed here that Hg concentrations in perch fillets/muscle tissue are similar to, or slightly higher than, those of whole fish, as reported by other studies (Scheuhammer & Blancher 1994, Haines et al.1992, Becker & Bigham 1995). In Maine, yellow perch from several lakes had an average fillet Hg concentration of 0.28 µg/g (Stafford & Haines 1997). While total Hg was higher than in our study, the fish sampled were also somewhat larger and older (23 cm, 6.6 years). Fillets of four- to five-year-old yellow perch in Massachusetts lakes had a mean Hg concentration of 0.31 µg/g (Mass. DEP 1997), while perch from an Ontario lake had a mean muscle Hg concentration of 0.34 µg/g, and an average age of only 2.7 years (Wren & MacCrimmon 1986). Furthermore, Scheuhammer & Blancher (1994) reported that 17% of lakes studied in Ontario contained small yellow perch (<250 g) with a mean muscle Hg concentration of greater than 0.4 µg/g. In three lakes in the New York Adirondack Preserve, fillet concentrations were much higher, averaging 0.83 µg/g in fish ranging from 14-21 cm and 3-8 years of age (Heit et al. 1989). Farther west, four-year-old perch from a lake in Michigan averaged 0.80 µg/g Hg (Laarman et al. 1976) and two-year-old perch from 10 lakes in Wisconsin had a mean Hg concentration of 0.17 µg/g (Cope et al. 1990). Research in Europe on another perch species of comparable size, *Perca fluviatilis*, has shown similar Hg concentrations: 0.43 mg/kg in fish from a Norway river (Norheim et al. 1986) and 0.55 µg/g in fish from several remote lakes in Russia (Haines et al. 1992).

Table 5. Comparison of yellow perch mercury concentrations in various studies

Location	Mean Length/ Weight/Age	W/ F*	Mean Hg conc. (wet wt., ug/g)	Reference
Kejimkujik, NS (24 lakes)	12.0 cm, 26 g, 5.1 years	W	0.25	This study
East of Halifax, NS (5 lakes)	12.2 cm	W	0.26	Rutherford et al. (1998)
East of Halifax, NS (14 lakes)	15.5 cm	W	0.56**	Peterson et al. (1990)
Southwest NS (56 lakes)	15.6 cm	W	0.11**	Peterson et al. (1990)
New Brunswick (13 lakes)	13.5 cm	W	0.14	Rutherford et al. (1998)
New Brunswick (63 lakes)	15.9 cm	W	0.018**	Peterson et al. (1990)
Southwest NB (6 lakes)	17.7 cm	W	0.36	Barry (1998, unpubl. data)
Maine (several lakes)	23 cm, 6.6 yrs	F	0.28	Stafford & Haines (1997)
Massachusetts	4-5 years	F	0.31	Massachusetts DEP (1997)
Ontario (26 fish from 1 lake)	16.8 cm, 2.7 yrs	F	0.34	Wren & MacCrimmon (1986)
New York Adirondacks (3 lakes)	14-21cm, 3-8 yrs	F	0.83**	Heit et al. (1989)
Lake St. Clair, Michigan	3.9 years	F	0.80	Laarman (1976)
Upper Michigan (35 lakes)	5 years	F	0.27	Grieb et al. (1990)
Wisconsin (10 lakes)	10.5 cm, 2 yrs	W	0.17	Cope et al. (1990)
Russia (lakes, *Perca fluviatilis*)	13.8-21.9 cm	F	0.55	Haines et al. (1992)
Norway (river, *Perca fluviatilis*)	58-97 g	F	0.43	Norheim et al. (1986)

* W - whole fish analyzed; F - fillets analyzed
** dry weights converted to wet weight assuming 75% moisture content

Lakes containing yellow perch with high Hg concentrations are considered to pose a risk to nesting loon populations. Common loons generally prefer yellow perch to other fish as prey, and approximately 83% of their diet consists of fish weighing 5-75g, or measuring approximatly 8-18.5cm in length (Barr 1996). Scheuhammer et al. (1998) have identified a strong positive correlation between loon (adults and chicks) blood Hg concentrations and forage fish (yellow perch and sunfish) Hg concentrations. Further, prey fish Hg concentrations ≥0.3 µg/g have been associated with lower rates of nesting and poorer reproductive success in loons, with no young loons produced when Hg concentrations exceeded 0.4 µg/g in their prey (Barr 1986).

At Kejimkujik, 20 of the 24 lakes studied contained yellow perch that exceeded 0.3 µg/g Hg, and several had perch exceeding 0.4 µg/g Hg. Of all the fish collected in our study that fell within the size range of 8-18.5 cm favoured by loons, over 25% had Hg concentrations greater than 0.3 µg/g. Therefore, risks to loon reproduction are anticipated at Kejimkujik. Preliminary findings by Burgess et al. (1998b) indicate a strong correlation between Hg

concentrations in adult and juvenile loons and 10-cm yellow perch at Kejimkujik ($r = 0.79$ and 0.90, respectively) and an overall reduction in loon reproductive success associated with Hg exposure on 19 lakes in the Maritime provinces. It should be noted that, although Kejimkujik has loons with the highest blood Hg concentrations compared to other North American sites (Evers et al. 1998), it does not have the highest yellow perch Hg concentrations. Furthermore, the west-to-east trend of increasing loon blood Hg concentrations reported by Evers et al. does not appear to apply to perch Hg concentrations.

The potential risks to human health due to the elevated fish Hg concentrations at Kejimkujik have been addressed by d'Entremont et al. (1998), in a study on larger sport fish (brook trout and white perch). Fifteen percent of brook trout and 93% of white perch samples were reported to exceed the Health Canada safe consumption guideline of 0.5 µg/g, supporting a health advisory issued in 1996 to limit the consumption of fish greater than 25 cm. Similar health advisories have been issued throughout Nova Scotia, New Brunswick and several eastern States. Although most of the yellow perch in our study fall well below the health advisory levels of 0.5 µg/g and 25cm, and the species is not as desirable for sport fishing, they may be considered to pose an indirect human health risk as they are prey for larger sport fish species.

The elevated fish Hg concentrations in many remote or protected lakes, such as those in our study and many others throughout North America and Europe, often can not be attributed to local or regional pollution sources. Where nearby point-source pollution is not a factor, Hg accumulation in aquatic systems may be a result of both natural processes and long-range atmospheric transport and deposition of Hg from natural and anthropogenic sources. Anthropogenic sources include fossil-fuel fired electrical generating plants, waste incinerators, pulp and paper mills, gold mining operations, coal burners and ore refineries (Stober et al. 1995; Slemr & Langer 1992). These sources release Hg into the atmosphere primarily in its elemental form. Since elemental Hg is highly volatile, has a long residence time, and is susceptible to long range atmospheric transport on a global scale, these sources can affect terrestrial and aquatic systems far from the point of input to the atmosphere (MacKay et al. 1995).

Mason et al. (1994) suggest that the ratio of anthropogenic versus natural inputs to atmospheric Hg levels is currently 2:1. The primary natural sources of Hg emissions to the atmosphere are: volatilization in aquatic environments; volatilization from vegetation; degassing of geologic materials; expulsion of particulate matter and vapours during volcanic/geothermal activity; release from windblown dust, and wildfires (US EPA 1997).

This Hg is released primarily as elemental mercury vapour, and to a lesser extent as inorganic (oxides, sulphides, halides) and organic (methylmercury) vapours. A third source of atmospheric Hg is the ongoing re-release of Hg that had previously been deposited on land and in oceans, lakes and rivers (NESCAUM 1998).

Aside from direct atmospheric deposition to waterbodies, other sources of Hg in aquatic ecosystems are the leaching of naturally-occurring Hg into the water column, runoff containing Hg contamination from the terrestrial environment, and wetland drainage (Bishop et al. 1995; Rudd 1995). Swain et al. (1992) reported that up to 25% of Hg atmospherically deposited to terrestrial catchments is ultimately exported to lakes.

At Kejimkujik, total gaseous Hg (TGM) in ambient air between July 1996 and July 1997 ranged from 0.13 to 3.40 ng/m^3, similar to levels found in New Brunswick, elsewhere in North America, and globally (Beauchamp et al. 1997). The mean TGM for Kejimkujik was 1.49 ng/m^3, equivalent to the mean global average of approximately 1.5 mg/m^3. Total annual wet deposition at Kejimkujik for the same July 1996 - July 1997 period was estimated at 8.7 µg/m^2/yr, which is consistent with measurements in the northeastern U.S. (Hoyer et al. 1995) and within the range of values observed in Europe (Beauchamp et al. 1997; Steinnes & Andersson 1991). However, the annual wet deposition of Hg at Kejimkujik was more than double that observed in northwestern Ontario (St. Louis et al. 1995).

While it is difficult to estimate the extent to which long-range atmospheric deposition from anthropogenic sources contributes to the total Hg loading in Kejimkujik lakes, it likely plays a significant role. Lucotte et al. (1995) have hypothesized that lakes in southeast Canada have high Hg loadings because all have been under the direct influence of westerly winds carrying Hg from industrial centers in their paths. With the total gaseous Hg in the Northern Hemisphere increasing by a reported 1.46 ± 0.17% per year, atmospheric concentrations have doubled since the beginning of the 20th century (Slemr & Langer 1992). Furthermore, dated lake sediment cores have generally indicated a two- to three-fold increase in annual Hg deposition since pre-industrial times (prior to 1850) (Fitzgerald et al. 1998). At Kejimkujik, regional sources of Hg emissions (described by Doiron et al. 1998) are likely not a significant factor, as the majority are downwind from the Park. Natural sources may include the release from bedrock outcrops in the area. However, a study of Ordovician aged Meguma Group rocks (normally a source of natural Hg) at two Nova Scotia sites suggested that bedrock did not directly influence local terrestrial and aquatic Hg concentrations (Stehman 1978). Ongoing studies at Kejimkujik are using peat bog and lake sediment cores to determine the contemporary and historic depositional fluxes of Hg from the atmosphere. These will quantify the influence of anthropogenic and natural Hg

contributions, and evaluate the overall importance of Hg deposition to local Hg cycling (Fitzgerald 1998, Rutherford & Matthews 1998).

The total Hg content in yellow perch at Kejimkujik is positively and significantly correlated with fish age, fork length and weight. These relationships add support to the claim of other researchers that fish accumulate Hg as they age and grow (e.g. Driscoll et al. 1995; Scruton 1984; Parks et al. 1991). Uptake of Hg by fish is affected by a variety of factors, including the species of Hg ingested or absorbed, the diet of the fish, the rate of intake of water through the gills, and water/sediment chemistry.

While most of the Hg entering the aquatic environment is inorganic or elemental, bacteria in sediments and the water column convert it to organic methylmercury (MeHg), a species that is more bioavailable to fish and other organisms. MeHg is much more efficiently transferred to higher trophic levels of aquatic food chains than is inorganic Hg (Becker & Bigham 1995). The tendency of MeHg to bioaccumulate in the aquatic food chain has been demonstrated by many authors (e.g. Lasorsa & Allen-Gil 1995; Mason et al. 1995; Korhonen 1995). The majority of Hg measured in fish is in the MeHg form (Grieb et al. 1990, Scheuhammer et al. 1998). Becker & Bigham (1995) reported that the percentage of MeHg in total Hg measurements was 5% in water, 24% in phytoplankton, 26% in benthic macroinvertebrates, 40% in zooplankton and 96% in several species of fish. We assumed in our study that total Hg measurements for the yellow perch were likely comprised almost entirely of MeHg.

The magnitude of Hg concentrations in fish depends on a number of factors including species, length, weight, age and prey. Since Hg concentrations increase at higher levels of the food web, the trophic level of food in the diet of a fish strongly affects the amount of Hg it accumulates.

Yellow perch are fairly opportunistic in what they eat, with their diet changing with size and season. The young feed on cladocerans, ostracods and chironomid larvae, and by the end of their first year, had added dragonfly nymphs, Ephemoeroptera, molluscs, and small fishes to their diet. Older fish consume mainly chironomid larvae, decapods and the eggs and young of a wide variety of fishes (Scott & Crossman 1973). As an example of seasonal variation, Rodgers & Qadri (1982) reported that yellow perch eat benthic invertebrates throughout the summer, with zooplankton important in June and fish in August and September. In Kejimkujik lakes, Hg concentrations in predatory benthic invertebrates have been measured at approximately 0.028 µg/g, or roughly one-tenth the concentration of Hg in yellow perch (Gabriel 1998).

As yellow perch have a voracious appetite and very effective feeding behaviour, they often compete with other species (such as trout and bass) and with themselves, which can lead to stunting of growth (Scott & Crossman 1973). The average growth rate of the perch in our study (i.e. 12 cm at 5.1 years) is somewhat lower than rates reported elsewhere in North America (Scott & Crossman 1973, Stafford & Haines 1997, Wren & MacCrimmon 1986), but is consistent with other Nova Scotian studies (Rutherford et al. 1998, Peterson et al. 1990, Scott and Crossman 1973). Peterson et al. suggested that repression of growth in earlier years was likely due to high population densities in Nova Scotia lakes and subsequent growth stunting, rather than environmental effects such as high lake acidity.

In addition to ingestion of prey, Hg is taken up by fish through the gills and skin, with the rate of Hg transport affected by the efficiency of Hg intake from water, the concentration of MeHg in the water and the rate of water movement through the gills and skin (Korhonen 1995). The proportion of Hg that is obtained directly from water is believed to be approximately 10-15% (Hall et al. 1997, Rodgers 1994).

The uptake and bioaccumulation of Hg and MeHg by all trophic levels of aquatic biota through passive diffusion, inhalation or ingestion is influenced by water chemistry. Correlations have been identified between Hg in the food chain and water pH, colour, dissolved organic carbon (DOC), total organic carbon (TOC), hardness, iron content, and presence of other heavy metals (Wren & Stokes 1988; McMurtry et al. 1989, Richardson et al. 1995). Other factors affecting Hg uptake include physical parameters such as water flow rate and watershed/lake area, which are positively correlated with Hg in fish (Bruce & Spencer 1979; Bentzen et al 1996).

The lakes in Kejimkujik National Park are comprised of oligotrophic, shallow (mean depth <4m) well mixed lakes, only a few of which show thermal stratification during the summer. Total Hg in the water of the 24 lakes studied ranged from 0.87 to 7.40 ng/L. These water concentrations correlated strongly with TOC ($r = 0.90$), supporting the claim by others that inorganic and organic Hg species associate with cation complexation sites on TOC compounds (e.g. Driscoll et al. 1994, Clair et al. 1998, Scherbatskoy et al. 1998). TOC, comprised of both particulate matter and a dissolved fraction (DOC), is normally a product of the breakdown of plant organic matter in forest and wetland soils to small molecules that are transported to streams and rivers by runoff processes. TOC levels in Kejimkujik's brown-water lakes have historically been higher than in other lakes in Nova Scotia and elsewhere in Atlantic Canada, with levels up to 25 mg/L. In our study they ranged from 2.55 to 17.01 mg/L. The lakes with high TOC concentrations (i.e. highly coloured lakes) tended to have higher Hg content than clear lakes and it is likely that much of the Hg was

bound to the organic fraction. Gill & Bruland (1990) have demonstrated that the majority of total Hg in water is bound to suspended particles.

At Kejimkujik, water Hg concentrations accounted for only 27% of the variation in fish Hg concentrations when compared to mean size-adjusted values for 12 cm perch ($p = 0.009$, $r = 0.52$, $r^2 = 0.27$). The ultimate accumulation by fish of Hg from the water column is partially affected by water chemistry, which influences Hg speciation and uptake at various levels of the food chain (Mason et al. 1994). Several studies suggest that lake TOC plays a very important role, as it:

1. provides a mechnism for the movement of bound Hg from terrestrial catchments to lakes, and from there throughout the water column (Scherbatskoy et al. 1998); and
2. provides nutrients to support the microbes that convert inorganic Hg into the more bioavailable and bioaccumulative MeHg (Kelly et al. 1995, Jackson 1991, Haines et al. 1992).

In our study, there was a significant positive correlation between yellow perch Hg and TOC ($p = 0.007$, $r = 0.54$), supporting the findings of other researchers (e.g. Clair et al. 1998, Richardson et al. 1995, Gill et al. 1990). The above-described mechanisms appear to be more significant in affecting fish Hg concentrations than the fact that high DOC is also associated with diminished bioavailability of Hg to aquatic biota because it so strongly binds Hg (Choi et al. 1998; Driscoll et al. 1995; Back & Watras 1995).

The variably acidic nature of the poorly-buffered Kejimkujik lakes (pH range of 4.29-5.90) may also affect Hg levels in the food web. There was a significant negative correlation between perch Hg concentrations and lake pH ($p = 0.003$, $r = -0.58$) and alkalinity in our study. The effect of lake pH on the Hg concentrations in biota has been extensively studied, and often significant negative correlations were found (e.g. Scheuhammer & Blancher 1994, Haines et al. 1995, Suns & Hitchin 1990). Haines et al. (1992) hypothesized that these correlations may be due to: (a) increased deposition of Hg from the atmosphere; (b) increased input of Hg from terrestrial ecosystems; (c) increased solubility of Hg in acidic water; (d) increased in-lake production of MeHg; (e) increased permeability of fish gills to Hg; and/or (f) decreased DOC content.

An additional factor in the uptake of Hg by fish may be the presence of other heavy metals in the water column. For example, high aluminum content may reduce the complexing of MeHg with DOC and enhance MeHg bioavailability (Driscoll et al. 1995). At Kejimkujik, yellow perch Hg concentrations were positively correlated with both aluminum and iron concentrations ($r = 0.52$ and 0.48, respectively). As these metals also tend to complex with sites on organic compounds, and in our study are correlated with TOC ($p<0.001$, $r =0.70$

and 0.64), these correlations might also simply be a direct result of the TOC content of the water.

Lake physical factors that may affect fish Hg concentrations include terrestrial drainage size/lake volume ratios, damming or impoundment of lakes (which raises the water level), lake size, and latitude (Scheuhammer & Blancher 1994, Suns & Hitchin 1990, Jackson 1991, Bentzen et al. 1996, Anderson et al. 1995). There was no correlation between lake size or maximum depth and perch Hg concentrations in our study. Furthermore, Grafton Lake, which was impounded for over 50 years until 1995, did not contain perch with above average Hg concentrations. This is contrary to a recent study on white perch and brook trout, in which the fish from Grafton Brook had the highest Hg concentrations among the watercourses studied (d'Entremont et al. 1998). Other studies have demonstrated that flooding of aquatic systems during impoundment accelerates the natural leaching rate of Hg and that the return of Hg to levels similar to those in other lakes in a watershed may take up to 20 years after impoundment (Bruce & Spencer 1979, Anderson 1995).

At Kejimkujik, sample location was highly significant ($p<0.00001$) when explaining differences in perch Hg concentrations. This indicates that levels of Hg contamination and uptake by fish varied among the Kejimkujik lakes, and supports the claim that yellow perch tend to stay within a relatively small range, rather than move amongst lakes in a watershed (Scott & Crossman 1973). The perch growth rates (measured as increasing fork length or weight gain with age) were also significantly different between lakes ($p<0.00001$), and increases in fish length with age was a significant factor in the different rates of Hg accumulation ($p=0.026$). Growth rates can be affected by stunting due to overcrowding in a lake (Scott & Crossman 1973), and fluctuations in prey availability due to lake chemistry. Increasing acidity of lake water, for example, may depress the numbers of acid-intolerant organisms relied upon by the more acid-tolerant yellow perch for food (Heit et al. 1989, Schofield & Driscoll 1987).

When lakes were grouped according to watershed, there was a significant difference ($p<0.001$) in mean size-adjusted perch Hg concentrations among the five watersheds. This was not accounted for by watershed area (i.e. there was no increase in Hg with watershed size), as has been reported by Bentzen et al. (1996). However, the following water chemistry parameters were significant in explaining the differences in perch Hg concentrations between watersheds: TOC ($p=0.020$), colour ($p=0.040$), pH ($p=0.020$) and alkalinity ($p=0.007$). This is consistent with the correlations between fish Hg and water chemistry parameters for the 24 lakes.

REFERENCES

Anderson, M.R., D.A. Scruton, U.P. Williams and J.F. Payne (1995). Mercury in fish in the Smallwood Reservoir, Labrador, twenty-one years after impoundment. Water, Air, Soil Pollut. 80:927-930.

Back, R.C and C.J. Watras (1995). Mercury in zooplankton of northern Wisconsin lakes: taxonomic and site-specific trents. Water, Air and Soil Pollution. 80:931-938.

Barr, J.F. (1986). Population dynamics of the common loon (*Gavia immer*) associated with mercury-contaminated waters in northwestern Ontario. Occasional Paper 56. Canadian Wildlife Service, Ottawa, ON.

Barr, J.F. (1996). Aspects of common loon (*Gavia immer*) feeding biology on its breeding ground. Hydrobiologia 321:119-144.

Beauchamp, S., N. Burgess, A. d'Entremont, R. Tordon, W. Schroeder and J. Abraham (1997). Mercury in Air, Water and Biota in Kejimkujik National Park, Nova Scotia, Canada. Presented at the Third International Conference of Science and the Management of Protected Areas, May 12-16, 1997. Calgary, Alberta.

Becker, D.S. and G.N. Bigham (1995). Distribution of mercury in the aquatic food web of Onondaga Lake, New York. Water, Air, Soil Pollut. 80:563-571.

Bentzen, E., D.R.S. Lean, D. Mackay and M. Amyot (1996). Mercury in Ontario lake trout: role of food webs and watershed characteristics. Program Abstracts for the American Society of Limnology and Oceanography 1996 Annual Meeting, University of Wisconsin-Milwaukee.

Bishop, K., Y-H. Lee, C. Pettersson and B. Allard (1995). Methylmercury output from the Svartberget catchment in northern Sweden during spring flood. Water, Air and Soil Pollution. 80:445-454.

Bruce, W.J. and K.D. Spencer (1979). Mercury levels in Labrador fish, 1977-78. Canadian Industry Report of Fisheries and Aquatic Sciences, No.111. St. John's, Newfoundland.

Burgess, N., T. Diamond, N. Benjamin, J. Kerekes, M. Duggan, D. Evers and J. Kaplan (1996). High mercury levels in common loons breeding in the Maritimes. Poster presented at the Second Annual EMAN Science Conference, Halifax, NS. January 17-20, 1996.

Burgess, N., S. Beauchamp, G. Brun, T. Clair, C. Roberts, L. Rutherford, R. Torden and O. Vaidya (1998a). Mercury in Atlantic Canada: A progress report. Mercury Team, Regional Science Coordinating Committee, Environment Canada, Atlantic Region. Sackville, NB.

Burgess, N.M., D.C. Evers and J.D. Kaplan (1998b). Mercury levels in the blood of common loons breeding in the Maritimes and their prey. In Mercury in Atlantic Canada: A progress report. Mercury Team, Regional Science Coordinating Committee, Environment Canada, Atlantic Region. Sackville, NB.

Choi, M.H., J.C. Cech Jr. And M.C. Lagunas-Solar (1998). Bioavailability of methylmercury to Sacramento blackfish (*Orthodon microlepidotus*): dissolved organic carbon effects. Environ. Toxicol.Chem. 17(4):695-701.

Clair, T.A., N. Burgess, G.L. Brun and D. Léger (1998). The relationship between organic carbon, pH, total mercury and location in Atlantic Canada lakes. In Mercury in Atlantic Canada: A progress report. Mercury Team, Regional Science Coordinating Committee, Environment Canada, Atlantic Region. Sackville, NB.

Cope, W.G., J.G. Wiener and R.G. Rada (1990). Mercury accumulation in yellow perch in Wisconsin seepage lakes: relation to lake characteristics. Environ. Toxicol. Chem. 9:931-940.

d'Entremont, A., J. Carter, N. Burgess, C. Drysdale, G. Brun and S. Beauchamp (1998). Mercury concentrations in brook trout and white perch from Kejimkujik National Park, Nova Scotia. Parks Canada Technical Reports in Ecosystem Science Series, #018. Halifax, NS.

Doiron, C.C., C.G. Roberts and L.A. Rutherford (1998). Atlantic Canada regional anthropogenic mercury emissions. In Mercury in Atlantic Canada: A progress report. Mercury Team, Regional Science Coordinating Committee, Environment Canada, Atlantic Region. Sackville, NB.

Driscoll, C.T., C. Yan, C.L. Schofield, R. Munson and J. Holsapple (1994). The mercury cycle and fish in the Adirondack Lakes. Environ. Sci. Technol. 28(3):136A-143A.

Driscoll, C.T., V. Blette, C. Yan, C.L. Schofield, R. Munson and J. Holsapple (1995). The role of dissolved organic carbon in the chemistry and bioavailability of mercury in remote Adirondack lakes. Water, Air and Soil Pollution. 80:499-508.

Environment Canada (1982). Analytical methods manual. Inland Waters Directorate, Environment Canada, Ottawa, ON.

Evers, D.C., J.D. Kaplan, M.W. Meyer, P.S. Reaman, W.E. Braselton, A. Major, N. Burgess, and A.M. Scheuhammer (1998). Geographic trend in mercury measured in common loon feathers and blood. Environ. Toxicol. Chem. 17(2):173-183.

Fitzgerald, W.F., D.R. Engstrom, R.P. Mason, E.A. Nater (1998). The case for atmospheric mercury contamination in remote areas. Environ. Sci. Technol. 32:1-7.

Fitzgerald, W.F. (1998). Contemporary and historical eolian depositional fluxes of mercury: Archival records from ombrotrophic bogs and lake sediments. Research Proposal KEJ-9708, Parks Canada Atlantic Region, Halifax, NS.

Gabriel, C.-E. (1998). The accumulation of mercury in aquatic ecosystems at Kejimkujik National Park, NS. Bachelor of Science Honours Thesis, Department of Biology, Dalhousie University, Halifax, NS. 70p.

Gill, G.A. and K.W. Bruland (1990). Mercury speciation in surface freshwater systems in California and other areas. Environ. Sci. Technol. 24:1392-1400.

Grieb, T.M., C.T. Driscoll, S.P. Gloss, C.L. Schofield, G.L. Bowie and D.B. Porcella (1990). Factors affecting mercury accumulation in fish in the upper Michigan peninsula. Environ. Toxicol. Chem. 9:919-930.

Haines, T.A., V. Komov and C.H. Jagoe (1992). Lake acidity and mercury content of fish in Darwin National Reserve, Russia. Environ. Pollut. 78:107-112.

Haines, T.A., V.T. Komov, V.E. Matey and C.H. Jagoe (1995). Perch mercury content is related to acidity and color of 26 Russian lakes. Water Air Soil Pollut. 85:823-828.

Hall, B.D., R.A. Bodaly, R.J.P. Fudge, J.W.M. Rudd and D.M. Rosenberg (1997). Food as the dominant pathway of methylmercury uptake by fish. Water, Air, Soil Pollut. 100:13-24.

Heit, M., C. Schofield, C.T. Driscoll and S.S. Hodgkiss (1989). Trace element concentrations in fish from three Adirondack lakes with different pH values. Water, Air, Soil Pollut. 44:9-30.

Hoyer, M., J. Burke and G. Keeler (1995). Atmospheric sources, transport and deposition of mercury in Michigan: Two years of event precipitation. Water, Air and Soil Pollution. 80:199-208.

Jackson, T.A. (1991). Biological and environmental control of mercury accumulation by fish in lakes and reservoirs of Northern Manitoba, Canada. Can. J. Fish. Aquat. Sci. 48:2449-2470.

Kelly, C.A., J.W.M. Rudd, V.L. St. Louis and A. Heyes (1995). Is total mercury concentration a good predictor of methylmercury concentration in aquatic systems? Water, Air, Soil Pollut. 80:715-724.

Korhonen, P., M. Virtanen and T. Schultz (1995). Bioenergetic calculation of mercury accumulation in fish. Water, Air and Soil Pollution. 80:901-904.

Laarman, P.W., W.A. Willford and J.R. Olson (1976). Retention of mercury in the muscle of yellow perch (*Perca flavescens*) and rock bass (*Ambloplites rupestris*). Trans. Am. Fish. Soc. 105(2):296-300.

Lasorsa, B. and S. Allen-Gil (1995). The methylmercury to total mercury ration in selected marine, freshwater and terrestrial organisms. Water, Air and Soil Pollution. 80:905-913.

Lucotte, M., A. Mucci, C. Hillaire-Marcel, P. Pichet and A. Grondin (1995). Anthropogenic mercury enrichment in remote lakes in northern Quebec. Water, Air, Soil Pollut. 80:467-476.

MacKay, D., F. Wania and W.H. Schroeder (1995). Prospects for modeling the behavior and fate of mercury, globally and in aquatic systems. Water, Air and Soil Pollution. 80:941-950.

Mason, R.P., W.F. Fitzgerald and F.M.M. Morel (1994). The biogeochemical cycling of mercury: Anthropogenic influences. Geochim. Cosmochim. Acta 58(15):3191-3198.

Mason, R.P., J.R. Reinfelder and F.M.M. Morel (1995). Bioaccumulation of mercury and methylmercury. Water, Air and Soil Pollution. 80:915-921.

Massachusetts Department of Environmental Protection (1997). Fish mercury distribution in Massachusetts lakes: final report. Boston, MA. 60p.

McMurtry, M.J., D.L. Wales, W.A. Scheider, G.L. Beggs and P.E. Dimond (1989). Relationship of mercury concentrations in lake trout (Salvelinus namaycush) and smallmouth bass (Micropterus dolomieui) to the physical and chemical characteristics of Ontario Lakes. Can. J. Fish. Aquat. Sci. 46:426-434.

Norheim, G., T. Hastein and E. Waasjo (1986). Mercury levels in fish in a river habitat after cessation of mercury contamination. Nord. Vet.-Med. 38:298-302.

NESCAUM (1998). Northeast States and Eastern Canadian Provinces Mercury Study: A framework for action. Northeast States for Coordinated Air Use Management, Boston, MA.

Parks, J.W., C. Curry, D. Romani and D.D. Russell (1991). Young northern pike, yellow perch and crayfish as bioindicators in a mercury contaminated watercourse. Environmental Monitoring and Assessment. 16:39-73.

Peterson, R.H., A. Sreedharan and S. Ray (1990). Accumulation of trace metals in three species of fish from lakes in New Brunswick and Nova Scotia (Canada): Influence of pH and other chemical parameters. Water Poll. Res. J. Canada. 24:100-117.

Richardson, M., M. Egyed and D.J. Currie (1995). Human exposure to mercury may decrease as acidic deposition increases. Water, Air, Soil Pollut. 80:31-39.

Rodgers, D.W. and S.U. Qadri (1982). Growth and mercury accumulation in yearling yellow perch, *Perca flavescens*, in the Ottawa River, Ontario. Env. Biol. Fish. 7(4):377-383.

Rodgers, D.W. (1994). You are what you eat and a little bit more: Bioenergetics-based models of methylmercury accumulation in fish revisited. In Mercury Pollution: Integration and Synthesis; International Conference on Mercury as a Global Pollutant. Lewis Publishers, Boca Raton, FL. p. 427-439.

Rudd, J.W.M (1995). Sources of methyl mercury to freshwater ecosystems: a review. Water, Air and Soil Pollution. 80:697-713.

Rutherford, L.A., G. Brun, G.R.J. Julien, F. Hebert and R. Mroz (1998). Mercury in yellow perch study - Progress report. Mercury in Atlantic Canada: A progress report. Mercury Team, Regional Science Coordinating Committee, Environment Canada, Atlantic Region. Sackville, NB.

Rutherford, L.A. and S.L. Matthews (1998). Historical mercury deposition in ombrotrophic bogs. In Mercury in Atlantic Canada: A progress report. Mercury Team, Regional Science Coordinating Committee, Environment Canada, Atlantic Region. Sackville, NB.

Scherbatskoy, T, J.B. Shanley and G.J. Keeler (1998). Mercury transport in a forested catchment. Water, Air, Soil Pollut. 105:427-438.

Scheuhammer, A.M., C.M. Atchison, A.H.K. Wong and D.C. Evers (1998). Mercury exposure in breeding common loons (*Gavia immer*) in Central Ontario, Canada. Environ. Toxicol. Chem. 17(2):191-196.

Scheuhammer, A.M. and P.J. Blancher (1994). Potential risk to common loons (*Gavia immer*) from methylmercury exposure in acidified lakes. Hydrobiologia 279/280:445-455.

Schofield, C.L. and C.T. Driscoll (1987). Fish species distribution in relation to water quality gradients in the North Branch of the Moose River Basin. *Biogeochem.* 3:63-85.

Scott, W.B. and E.J. Crossman (1973). Freshwater Fishes of Canada. Bulletin 184. Fisheries Research Board of Canada, Ottawa.

Scruton, D.A. (1984). A survey of selected lakes in Labrador, with an assessment of lake status and sensitivity in relation to acid precipitation. Canadian Technical Report of Fisheries and Aquatic Sciences 1296. St. John's, Newfoundland.

Slemr, F. and E. Langer (1992). Increase in global atmospheric concentrations of mercury inferred from measurements over the Atlantic Ocean. *Nature*. 355:434-436.

Stafford, C.P. and T.A. Haines (1997). Mercury concentrations in Maine sport fishes. Trans. Am. Fish. Soc. 126:144-152.

Stehman, C.F. (1978). Investigation of geochemically released mercury in the aquatic and terrestrial ecosystems. Surveillance Report EPS-5-AR-78-6. Environment Canada, Environmental Protection Service, Atlantic Region. 76p.

Steinnes, E and E. Andersson (1991). Atmospheric deposition of mercury in Norway: Temporal and spatial trends. Water, Air and Soil Pollution. 56:391-404.

St. Louis, V.L., J.W.M. Rudd, C.A. Kelly and L.A. Barrie (1995). Wet deposition of methyl mercury in northwestern Ontario compared to other geographic locations. Water, Air and Soil Pollut. 80:405-414.

Stober, Q.J., R.D. Jones and D.J. Scheidt (1995). A multi-media canal pilot study. Water, Air and Soil Pollution. 80:991-1001.

Suns, K. and G. Hitchin (1990). Interrelationships between mercury levels in yearling yellow perch, fish condition and water quality. Water, Air, Soil Pollut. 65:255-265.

Swain, E.B., D.R. Engstrom, M.E. Brigham, T.A. Henning and P.L. Brezonik (1992). Increasing rates of atmospheric mercury deposition in midcontinental North America. Science 257:784-787.

United States Environmental Protection Agency (1997). Mercury Study Report to Congress, Volume II. An inventory of anthropogenic mercury emissions in the United States. Washington, D.C.

Wren, C.D. and H.R. MacCrimmon (1986). Comparative bioaccumulation of mercury in two adjacent freshwater ecosystems. Wat. Res. 20(6):763-769.

Wren, C.D. and P.M. Stokes (1988). Depressed mercury levels in biota from acid and metal stressed lakes. Ambio 17(1):28-30.

Personal Communications

Barry, E. (1998). New Brunswick Cooperative Fish and Wildlife Research Unit, Biology Department, University of New Brunswick, Fredericton, NB.

Rutherford, L. (1998). Environmental Protection Branch, Environment Canada Atlantic Region, Dartmouth, NS.

Parcs Canada, région de l'Atlantique, produira trois séries de rapports en sciences des écosystèmes afin de communiquer de nouvelles données scientifiques, de consigner des données scientifiques, et de résumer les connaissances existantes ou de formuler des recommandations d'ordre technique. La fonction principale et le public visé détermineront la série dans laquelle un rapport sera publié. Chaque série contiendra des informations scientifiques et techniques qui viendront enrichir les connaissances existantes, mais ne pourraient être publiées dans les revues professionnelles en raison de leur présentation.

- ***Les Rapports techniques en sciences des écosystèmes - Parcs Canada*** favoriseront la diffusion à grande échelle d'information scientifique et technique tirée des études spéciales effectuées par Parcs Canada. La matière traitée et la série reflètent l'intérêt et les politiques de Parcs Canada dans de nombreux aspects des sciences des écosystèmes. La série comprendra des inventaires d'écosystèmes, des inventaires de ressources, des études diverses, des relevées sur des espèces ou des guildes et des concepts innovateurs de gestion.
- ***Les Rapports d'études en matière de sciences des écosystèmes - Parcs Canada*** permetteront la publication de comptes rendus, de bibliographies et d'études d'options en matière de gestion faites par Parcs Canada. Les descriptions et les analyses de ressources sont aussi publiées dans cette série, en entier ou en partie.
- ***Les Rapports de surveillance et de données relatives aux écosystèmes - Parcs Canada*** offriront un moyen de présenter des compilations de données sans analyse détaillée. En général, ce genre de compilation sert à appuyer des publications scientifiques ou des rapports techniques en sciences des écosystèmes. Parcs Canada publiera dans cette série des données brutes qui ne sont pas inclues dans une banque de données nationale et qui méritent l'archivage.

Rapports en sciences des ecosystèmes sont publiés dans la langue officielle choisie par l'auteur en fonction du public visé, avec un résumé dans la deuxième language officielle.

Objectifs
Ces séries de rapports serviront à :

- communiquer les résultats des recherches effectuées en sciences des écosystèmes aux scientifiques et aux gestionnaires, ainsi qu'aux membres du public que les activités enterprises par Parcs Canada en écologie et en conservation intéressent.
- offrir des publications professionnelles, crédibles et précises qui seront soumises à l'évaluation par les pairs.
- favoriser la diffusion de l'information, la créativité, l'efficacité et le travail d'équipe dans les projets de recherche.

Évaluation par les pairs
Le rédacteur nommera deux lecteurs choisis, dans la mesure du possible, parmi le personnel scientifique de Parcs Canada, qui seront chargés de faire une critique de chaque manuscrit. On fera appel à des lecteurs de l'extérieur en raison de l'expertise exigée, du temps disponible et de l'objectivité nécessaire. Les lecteurs renverront le manuscrit au rédacteur en y joignant leurs commentaires par écrit. Le rédacteur renverra le manuscrit à son ou à ses auteurs avec les commentaires des lecteurs. L'auteur prendra connaissance des commentaires et tiendra compte de ceux avec lesquels il est d'accord, puis il retournera le manuscrit révisé au rédacteur en lui expliquant par écrit pourquoi il n'a pas tenu compte de certains commentaires. Le rédacteur enverra ensuite le manuscrit au garde de parc en chef, ou, s'il s'agit d'employés du bureau régional, au superviseur immédiat de l'auteur, pour faire approuver la publication et l'impression du manuscrit. Dans le cas de publications de moindre importance, le rédacteur peut, à sa discrétion, décider de ne pas avoir recours à des lecteurs; lui-même et le superviseur immédiat de l'auteur serviront alors de lecteurs. En cas de désaccord entre l'auteur et le rédacteur au sujet du manuscrit, c'est le gestionnaire ministériel principal qui tranchera.

Directives à l'intention des auteurs
Ces séries de rapports seront consacrées à la publication de travaux effectués dans la région de l'Atlantique en science des écosystèmes et seront mises à la disposition de tous les employés de Parcs Canada, du ministère du Patrimoine canadien, de leurs collaborateurs ou de toute personne qui travaille pour le compte de Patrimoine canadien.

Les auteurs soumettront au rédacteur régional une copie de leur manuscrit sur support en papier, une version sur disquette en WordPerfect Windows ou DOS et le nom de trois lecteurs éventuels qui ne connaissent pas le manuscrit.

Pour de plus amples renseignements, communiquez avec :

Neil Munro
Rédacteur des séries de Rapports

Parcs Canada
Historic Properties
Halifax (Nouvelle-Écosse)
B3J 1S9

(902) 426-2797
(FAX) 426-2728